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A PRELIMINARY WINDTUNNEL INVESTIGATION OF A WING TIP
STATIC PRESSURE AMPLIFICATION DEVICE(U) PRINCETON UNIV
N J DEPT OF AEROSPACE AND MECHANICAL SCIENCES..

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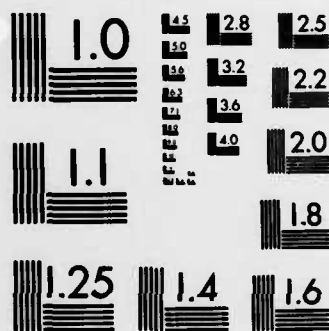
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Princeton University

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INVESTIGATION OF A WING TIP
STATIC PRESSURE
AMPLIFICATION DEVICE

D. C. Hazen

AMS Report No. 1191

October 1974



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SUMMARY

At the request of Flightcraft, Inc. of Old Lyme, Connecticut a series of windtunnel investigations of a model utilizing a variety of ducted wing tip sections was conducted in the Princeton University 4' x 5' windtunnel during September and October 1974. The ducted section consisted of a venturi entry portion that could be tested with a number of different discharge slots of various geometries. The tests showed that significant amplification of the free stream static pressure could be achieved; that in general the magnitude of the amplification factor decreased with angle of attack; the the magnitude of the factor could be significantly affected by the location and shape of the exit slot; and that the nature of the resulting signal was influenced by the location of the entry slot with relation to the leading edge.

INTRODUCTION

The basic concept of the "Laterlizer" device conceived of by Flightcraft, Inc. is to sense the difference in wing tip static pressures produced by any deviation from straight and level flight in either roll or yaw and to utilize this difference signal to activate a servo device producing the necessary corrective action to null the signal. As originally proposed, the device took the pressure signal from an unmodified tip and utilized a separate amplifier valve to control a servo operating on an external power source such as engine suction.

In order to increase the inherent safety, simplicity and reliability of the device, it was decided to explore the possibility of amplifying the magnitude of the pressures sensed to an extent that would permit them to drive a moderate sized servo directly. To do this a series of specially designed and constructed wing tips utilizing venturi sections of various geometries were tested on an existing semi-span model within the 4' x 5' windtunnel located in the Subsonic Aerodynamics Laboratory of the Department of Aerospace and Mechanical Sciences of Princeton University. Physically the tunnel is located on the Forrestal Campus about three miles distant from the main university campus.

DISCUSSION

The concept of operation of the "Lateralizer" is based on the concept of differential pressures being created between the wing tip venturis owing to deviations from straight to level flight.

In a steady-state turn, the low-slow wing tip will experience less venturi suction than the high-fast wing tip. This signal can be utilized to operate appropriate servos connected to the ailerons to produce a wing leveling restoring moment. The aileron on the semi-span receiving the most negative tip pressure signal will be deflected upwards to create this moment.

Should the wing be subjected to rolling velocities, venturi pressure differentials are created as a result of the changes of local angle of attack at the tip, the downgoing wing tip operating at a higher angle than the upgoing one. If the signal is such that the venturi pressure becomes more positive with increase in angle of attack, the arrangement which activates the servos to produce an upgoing aileron on the semi-span with the most negative tip pressure signal will again result in a wing leveling restoring moment.

Previous experience with early versions of the "Lateralizer" indicated that sideslip signals arising from misalignment of the

longitudinal axis with the flight path were not substantial. It was not known whether or not the effort to amplify these signals would affect this characteristic so a series of tests were conducted to evaluate the effect.

DESCRIPTION OF MODEL

The model employed for these tests had originally been built as a 1/5 scale model of a Cherokee semi-span. It had a span of 36.25" (corresponding to $b/2$ from the centerline of the airplane) a chord of 12.4", and a wing area of 3.125 square feet. The airfoil section employed was a 652 - 415, and as originally constructed, the model incorporated a linear twist from root to tip of -2° . Measurements showed that over the period of time that had passed since the model was constructed this had altered to -2.9° . Care was taken to check this periodically and during the course of the test period it was found to vary about this mean value by as much as $\pm .1^{\circ}$ depending upon weather conditions. Care was taken to record lift curve data on each run and since the values sought were of a comparative rather than absolute nature, all pressure data were presented as functions of the root section angle of attack with the angle of zero lift shifted as required to correspond with the base lift curve taken for the -2.9° twist case.

The model was mounted on the tunnel balance supports on a pivot axis running parallel to the .25 chord line and located .3 in below the lower surface. No end plate was used. Pressure tubing was led from the model through a fairing to the back wall of the test

section. (See photographs for details of model mounting arrangements.)

The configurations of the wing tip sections tested are illustrated by Figure I with the exception of the last configurations tested in which the venturi entrance was extended forward to the leading edge. This arrangement is illustrated by the photograph showing the forward quarter of the wing tip.

The lift curve of wing without wall corrections is shown in Figure III for Reynolds Nos. of $.9 \times 10^6$ and $.71 \times 10^6$. Over the range of angles of interest the results were not particularly sensitive to Reynolds Number and the lower value was employed during the test series.

TESTS

The test program was conducted in two parts. The first series of investigations were carried out from September 6, 1974 to September 12, 1974. The second series were conducted on October 8 and 9, 1974.

In summary the tests conducted were as follows:

<u>Test No.</u>	<u>Configuration</u>	<u>Comment</u>
1	Plain Wing	These tests were conducted to determine basic wing characteristics and Reynold Number effects.
2	Plain Wing	
3	Plain Wing	
4	P ₁	In this configuration the forward exit slot with the upstream lip located at .29 c was tested through $\alpha_r = 0^\circ$ to 16° with $\psi = 0^\circ$.
5	P ₁ 90L	In this configuration the exit slot was formed by a 90° elbow with its exit extended by a lip as shown in Figure I. The upstream lip was located at .24 c, α_r was varied from 0° to 16° and $\psi = 0^\circ$.

- | | | |
|----|-------------|--|
| 6 | P_1^{90} | The exit slot incorporated at 90° elbow with its forward lip flush with the lower surface located at .24 c α_r was varied from 0° to 16° and $\psi = 0^\circ$. |
| 7 | P_1^{90S} | A scoop was added to the 90° elbow in this configuration bringing the exit back to .29 c. The full range of α_r was investigated and $\psi = 0^\circ$. |
| 8 | P_1^{45L} | A lip as indicated in Figure I was added to the 45° elbow, moving the forward lip of the resulting exit slot to .28 c α_r was varied from 0° to 16° and $\psi = 0^\circ$. |
| 9 | P_1^{45} | A repeat of Test No. 8 with the lip removed and the exit slot flush with the under surface. The forward lip was at .26 c. |
| 10 | P_1^{45S} | A scoop moving the exit to the .31 c point was added. The full range of α was investigated with $\psi = 0^\circ$. |

- | | | |
|----|-------------|--|
| 11 | $P_1^{.45}$ | This was a repeat of Test No. 9 at a $RN = .9 \times 10^6$ to establish the effect on the tip pressures. |
| 12 | $P_1^{.45}$ | A repeat of Test No. 9 at $RN = .71 \times 10^6$, and $\psi = -10^\circ$. |
| 13 | $P_1^{.45}$ | A repeat of Test No. 12 with $\psi = +10^\circ$. |
| 14 | P_2 | In this configuration the mid chord slot shown in Figure I was utilized. The exit slot was flush with the lower surface with the forward lip at .45 c, α_r was varied between 0° and 16° . $\psi = 0^\circ$. |
| 15 | P_3 | A repeat of Test No. 14 with the aft slot utilized moving the forward lip to the .69 c point. Neither scoops nor lips were employed with these rearward slot locations. |
| 16 | P_1 | This was a repeat of Test No. 4 to check repeatability of results. |
| 17 | P_1^S | In this test, the scoop was added to the original P_1 configuration. |

18

$P_1 L$

The effect of a lip upon the performance of the original configuration was explored in this test.

The first set of tests concluded at this point.

During the data reduction and analysis following these tests, it was found that the angle of attack measuring and adjusting devices incorporated in the windtunnel balance system had become defective and had provided grossly inaccurate data from Test No. 10 onwards. A series of reruns, utilizing templates to properly establish the angle of attack showed that the previously obtained data could satisfactorily be plotted as a function of C_L and then referred to angle of attack by means of the lift curve of Figure III.

The second set of tests conducted on the basis of preliminary analysis of the initial 18 were conducted on October 8 and 9 after repairs had been made to the balance angle of attack mechanism. In summary they were as follows:

<u>Test No.</u>	<u>Configuration</u>	<u>Comment</u>
19	P_1	A repeat of Test No. 16 with the angle of attack varied from - 4 to + 18 ⁰ .

- | | | |
|----|------------|--|
| 20 | P_1 FE | Fundamentally the same configuration as Test No. 19 but with the venturi section entry faired with clay. |
| 21 | P_1 ESE | The ESE refers to extended sharp entry. In this configuration the venturi entry was moved forward to the leading edge thereby reducing the included angle from 90° to 40° . The entry was left sharp as in all previous tests except No. 20. |
| 22 | P_1 ESES | This was the configuration of Test No. 21 but with the downstream scoop added. |
| 23 | P_1 ERES | This was the same configuration as in the previous test with some minor improvements in the shaping of the interior venturi section. |

DISCUSSION OF TEST RESULTS

As shown by Figure IV the basic configuration, termed P_1 and initially investigated in Test No. 4, displayed an amplification of the freestream dynamic pressure by a factor of more than -4 at $\alpha_r = 0$ which dropped in a nonlinear manner to about -2.75 at $\alpha_r = 16^\circ$.

Although this was an improvement in amplification of approximately 4 over the values measured in flight on an unmodified Cessna 150 wing tip by the Griswold Company in 1966 during early tests of the "Lateralizer" concept, the nonlinear behavior of the signal was felt unacceptable. Of particular concern was the almost constant value of $\frac{P_v}{q}$ from $\alpha_r = 0^\circ$ to 4° . The flow condition producing this effect was difficult to isolate. The reduction in slope at the higher values of α_r appeared to result from local accelerations around the tip.

Later investigations were to cast considerable doubt upon these results, since with the exception of configuration P_3 which clearly was subjected to local flow accelerations around the tip, most configurations displayed the typical characteristics of an increase in amplification factor up to about 4° angle of attack (of the root) followed by an essentially linear decrease of amplification factor with further increases of α_r . Test No. 16 plotted in Figure 6 (along with a repeat of the results of Test No. 4) strongly suggests some form of experimental error existed

in Test No. 4. At the time, however, the results of Test No. 4 drove the nature of the following experiments. (Test No. 19 later showed both previous tests to be in error.)

Changing to a 90° elbow with an extended lip, increased the amplification factor by approximately 1.0 and somewhat alleviated the loss of slope at the higher angles. At low angles, however, a reversed slope appeared. Removing the lip, as in Test No. 6, reduced the magnitude of amplification significantly, but did not appreciably alter the shape of the curve. Adding a scoop restored the amplification somewhat but did not alter the variation with angle of attack.

The next configuration tried altered the 90° elbow to a 45° one initially with a lip. Although this provided a strong amplification of the signal it aggravated the slope reversal at low angles of attack. Removing the lip produced results virtually identical to those obtained with the 90° elbow with a flush exit. Adding the scoop restored the amplification somewhat but did not alter the slope reversal at low angles.

Figure V is a plot of the results of Tests Nos. 9, 11, 12 and 13. In each case the configuration was the same, the flush mounted 45° elbow exit slot. Tests 9 and 11 were run at two different Reynolds Numbers and the results are virtually identical, thereby justifying the decision to conduct the test series at only one value of Reynolds Number. Tests 12

and 13 were conducted to explore the magnitude of the signal change with yaw angle. Essentially zero at low values of α the difference grows virtually linearly with increasing angle of attack.

Figure VI is a graph of the variation of the amplification factor of the three basic venturi tunnel lengths. Because of the nature of the results with configurations P_2 and P_3 , as previously mentioned, configuration P_1 was reexamined, the repeated tests showing the more or less normal variation with α . Smoke tests confirmed the effect of the tip flow in the case of configuration P_3 . Again the addition of a lip or a scoop increased the amplification factor.

Analysis of the results of this test series not only disclosed difficulties with the windtunnel equipment, but suggested that perhaps the problems associated with signal reversal at the lower angles might be related more to the entrance conditions than to those at the exit. As a result the tests of series II were conducted.

Having been unable to trace where the errors of the previous tests with the P_1 configuration might have existed, the model and pressure were carefully checked and the results shown in Figure VII obtained. Because of the care exercised and the closeness of the results obtained on repeat runs, the data shown in Figure VII are considered to be reliable.

The rerun of configuration P_1 disclosed that the shape of the curve resulting from Test No. 16 was basically correct but that the magnitude of amplification was optimistic. Fairing the entrance to form a bell-mouth had, as expected, little effect. Reference to Figures IV and V will show that the results of these tests are nearly identical with those obtained with the $P_1 45$ and $P_1 90$ configurations, further building confidence in their validity.

Flow visualization studies showed that the character of the inlet flow altered at the lower angles of attack. The entry was extended to the leading edge. Test 21 showed that this effectively eliminated the signal reversal. It also reduced the slope of amplification factor versus angle of attack. A check with the flight test data of the Griswold Co. revealed that the slopes were similar (only slopes could be compared as the tunnel results were shown referenced to the root angle of attack and the flight results to an airplane angle of attack utilizing an entirely different wing).

Tests 22 and 23 confirmed that the addition of exit slot configuration changes applied to the tips with extended entry slots, could alter the amplification factor without altering the nature of its variation with angle of attack.

CONCLUSIONS AND RECOMMENDATIONS

Although these tests were only designed to provide a preliminary evaluation of the possibility of amplifying the wing tip pressure signal by means of a tip mounted venturi, the results of the second series seem encouraging enough to suggest that further tunnel testing be waived in favor of the investigation of a full scale tip section in flight.

No attempt has been made to establish whether or not the signal magnitude and variation with angle of attack are suitable for the "Lateralizer" application envisioned by Flightcraft, Inc. but it does appear that configurations can be developed that will provide amplifications of at least five times the values of static pressure measured on an unmodified tip.

In producing this type of amplification, these tests have shown that modification of the downstream exit slot can have a substantial effect upon the magnitude obtained, but that the leading edge plays a major role in determining the variation with angle of attack. As a very minimum an entry slot flush with the leading edge is required.

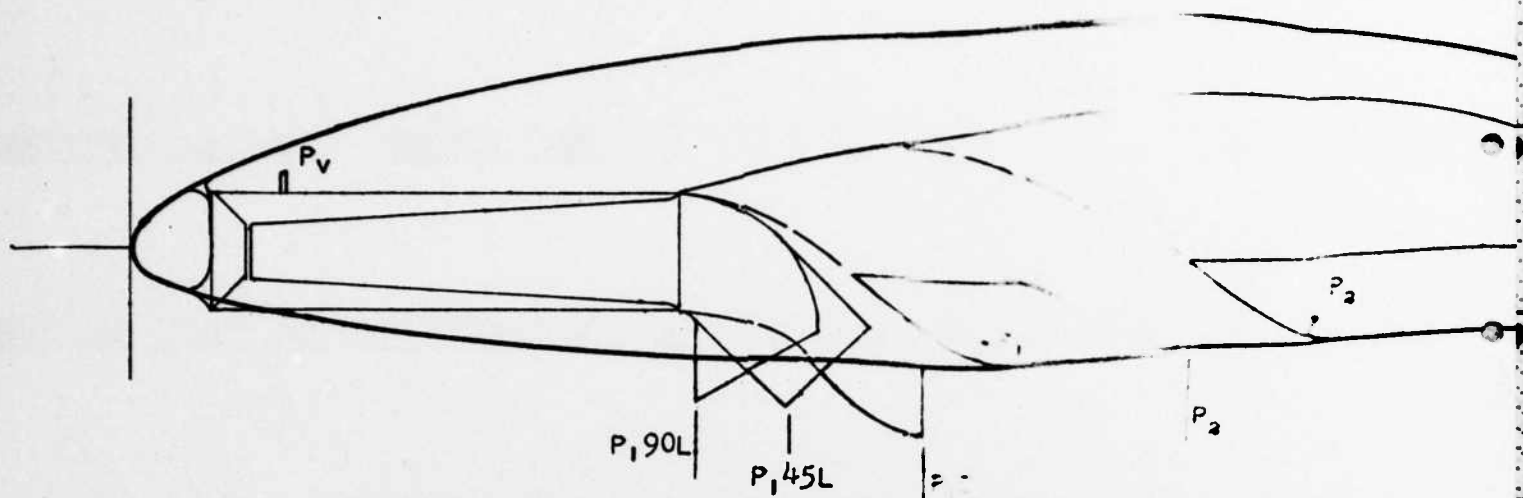


FIG. I WIND TUNNEL MODEL CONFIGURATIONS - FULL SCALE - MODEL 65-115

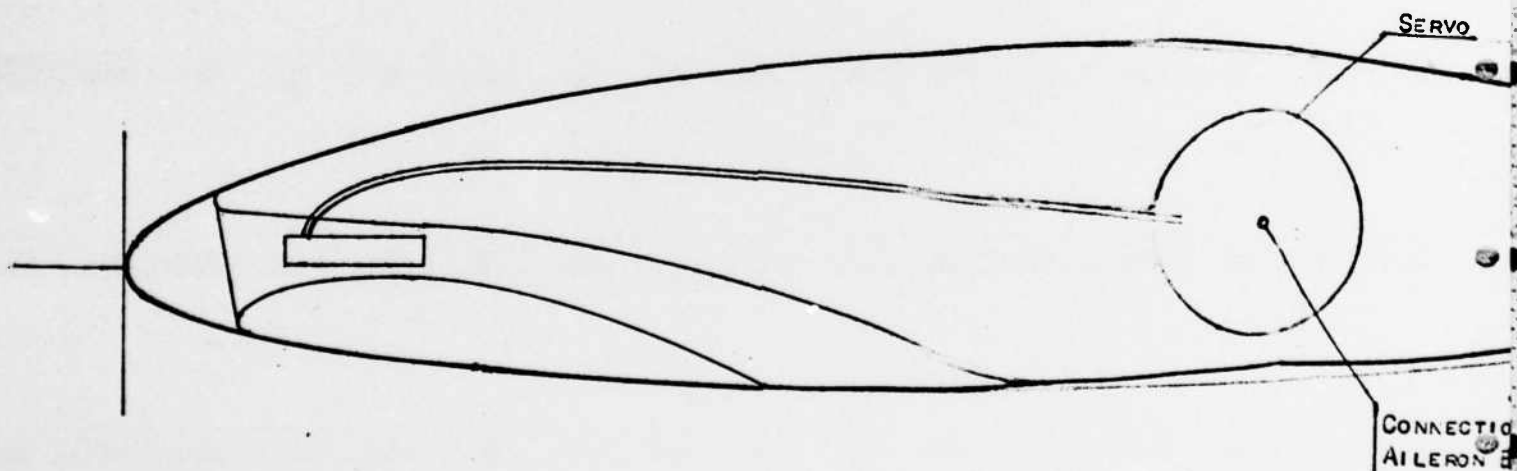
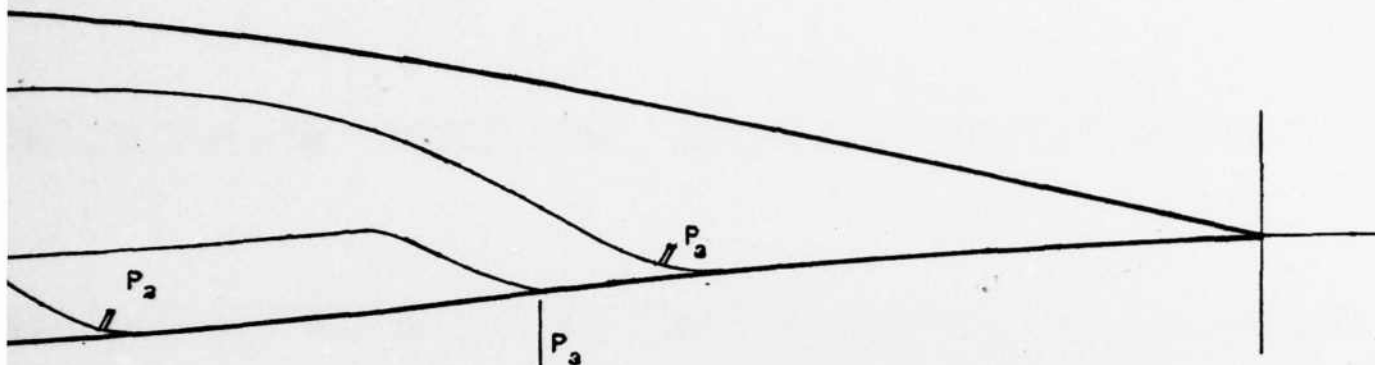


FIG. II SCHEMATIC TYPICAL OF COMPOUND VENTURI-SERVO SYSTEM - SCALE = 1:5



NOTES:

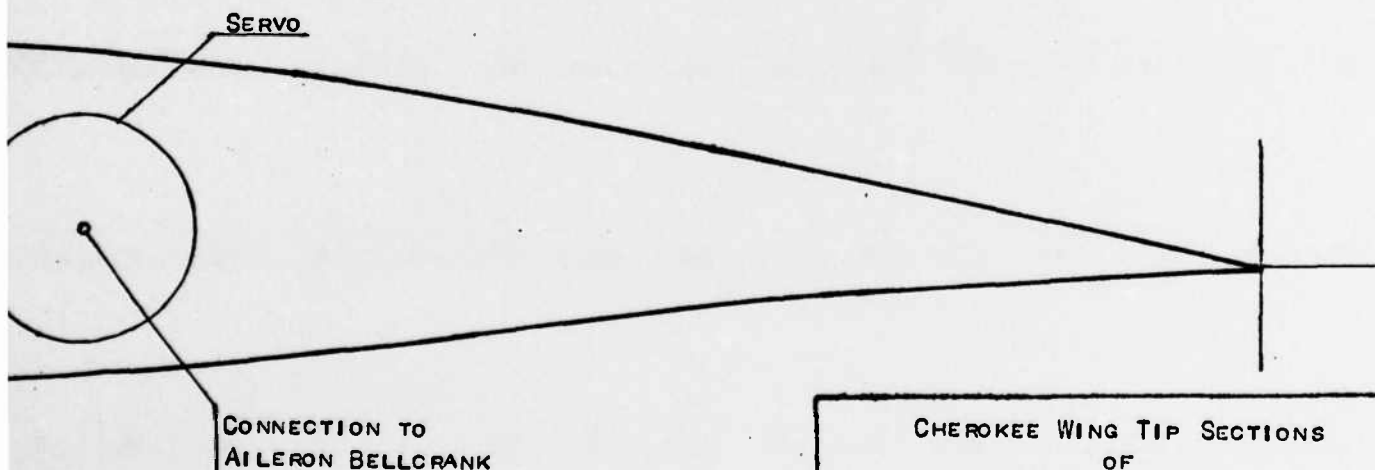
— — — — — REMOVABLE DUCT PORTIONS

COVER PLATES ARE TAPED OVER INOPERATIVE SLOT EXITS

PLASTICINE USED TO FAIR DUCTS WHERE REQUIRED

P_v - VENTURI PRESSURE TAP

$P_1 - P_2 - P_3$ - SLOT EXIT PRESSURE TAPS



CHEROKEE WING TIP SECTIONS
OF
SIMPLIFIED LATERALIZER SYSTEM

FLIGHTCRAFT INC.

OLD LYME, CONNECTICUT 9/16/74

CONTRACT NAS1-13499 7/17/74

DSGND-DRAWN-APPVD BY *RW*

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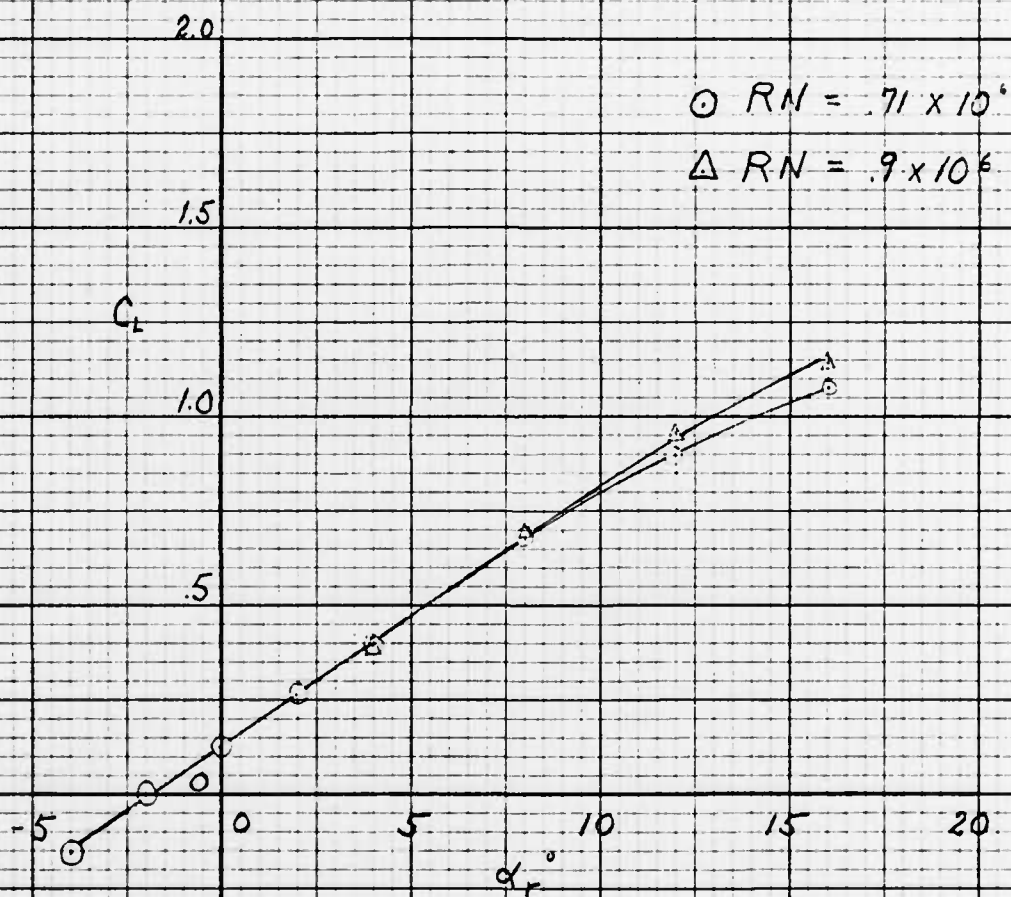


FIGURE III

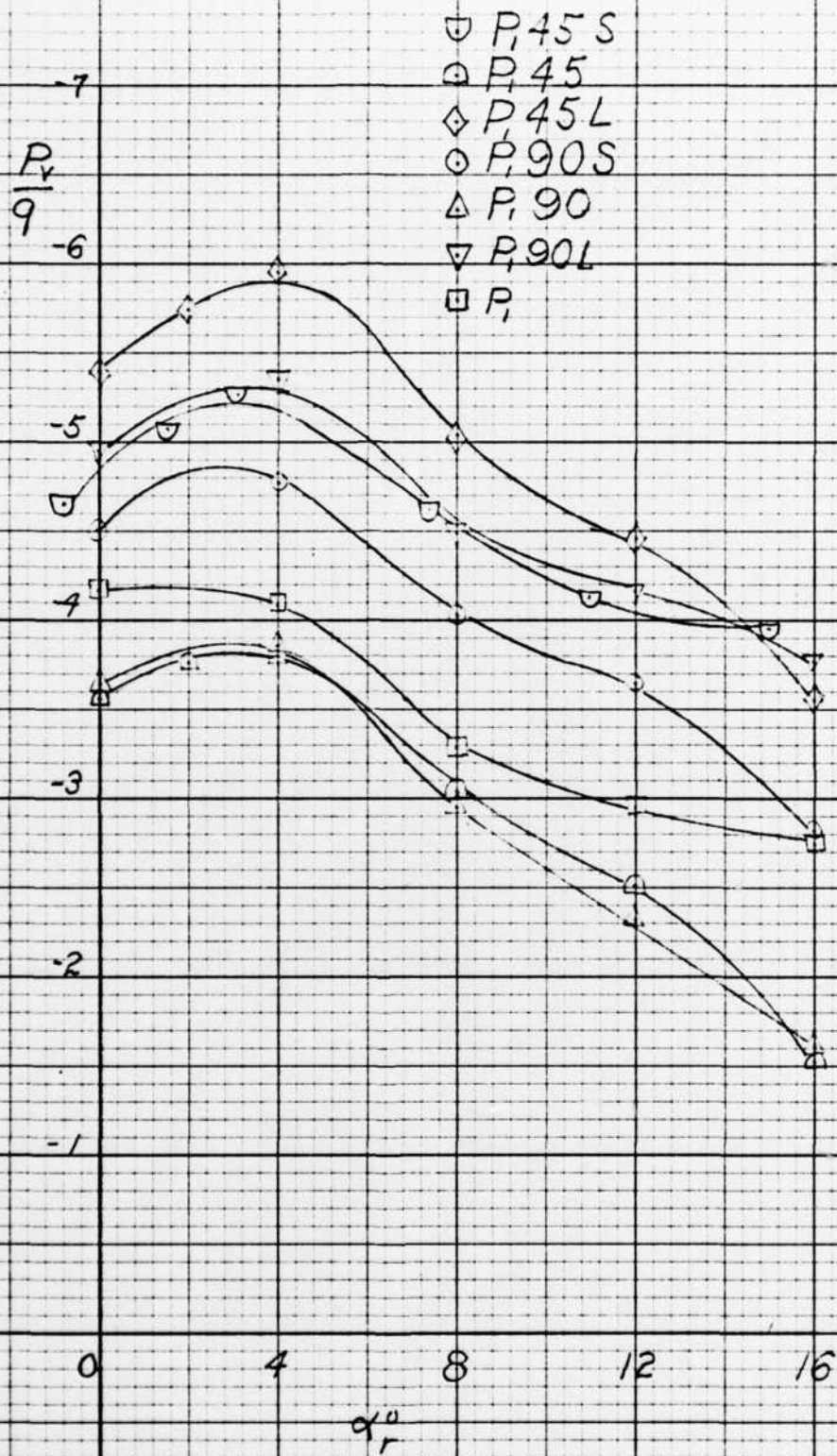


FIGURE IV

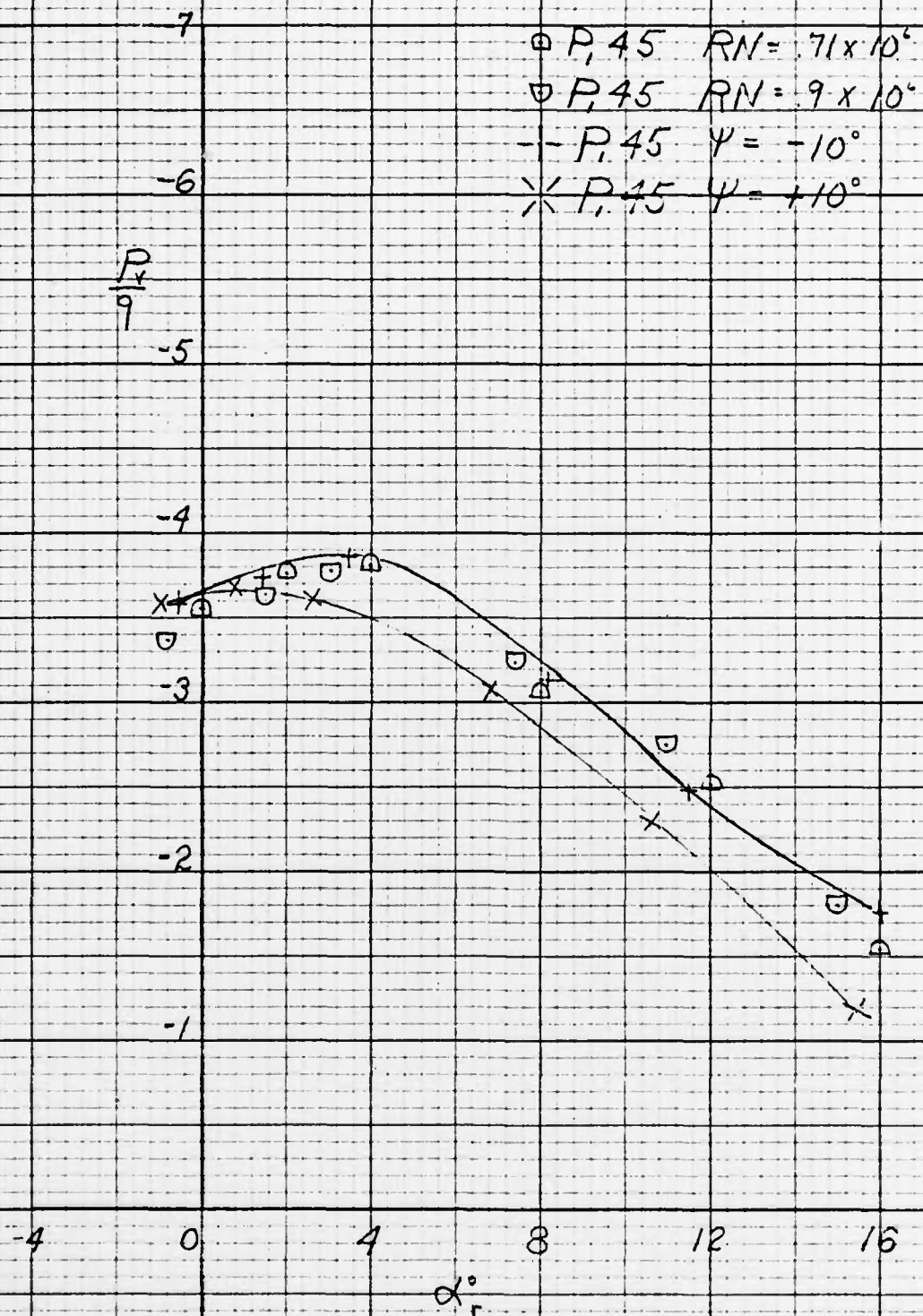


FIGURE V

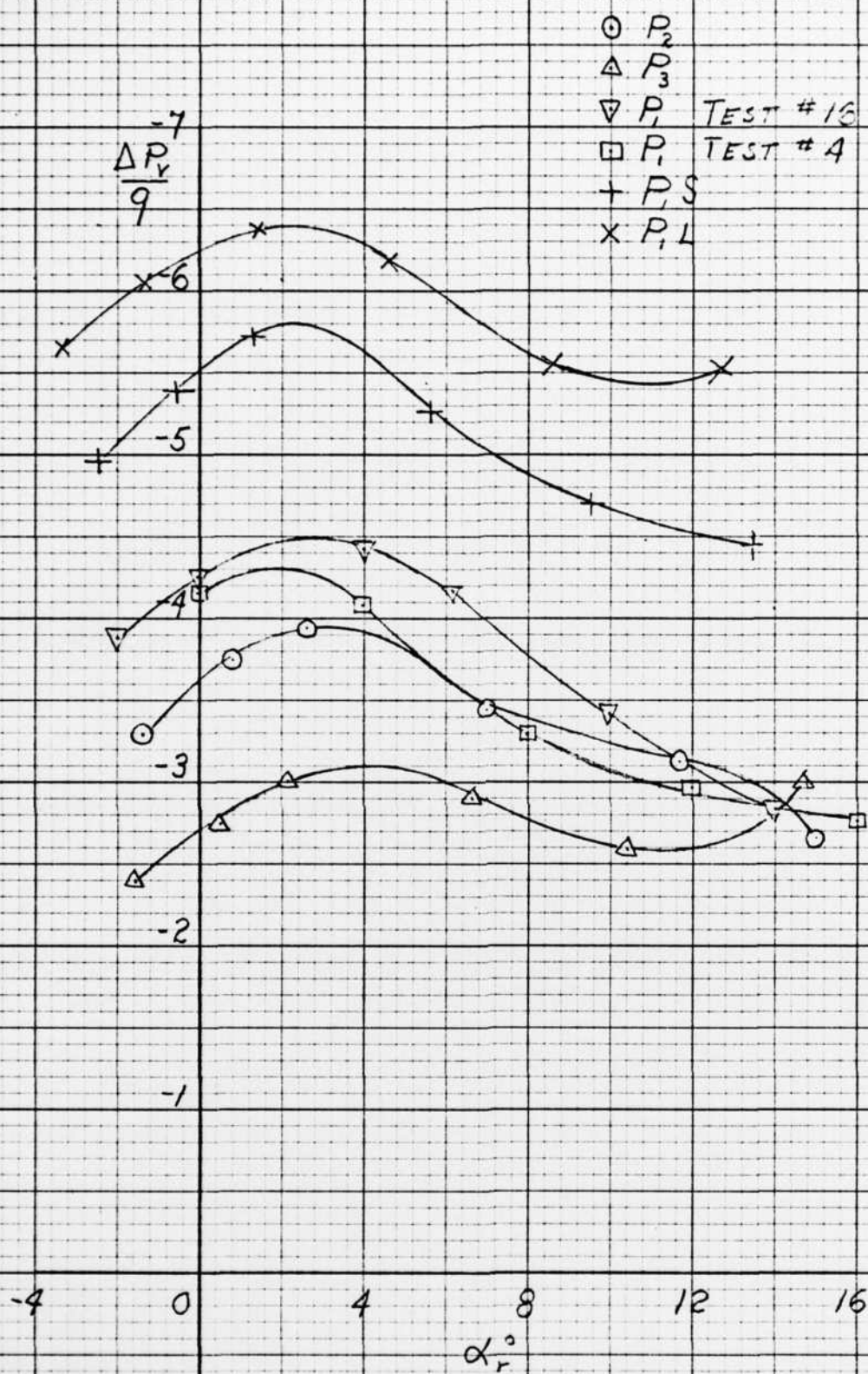


FIGURE VI

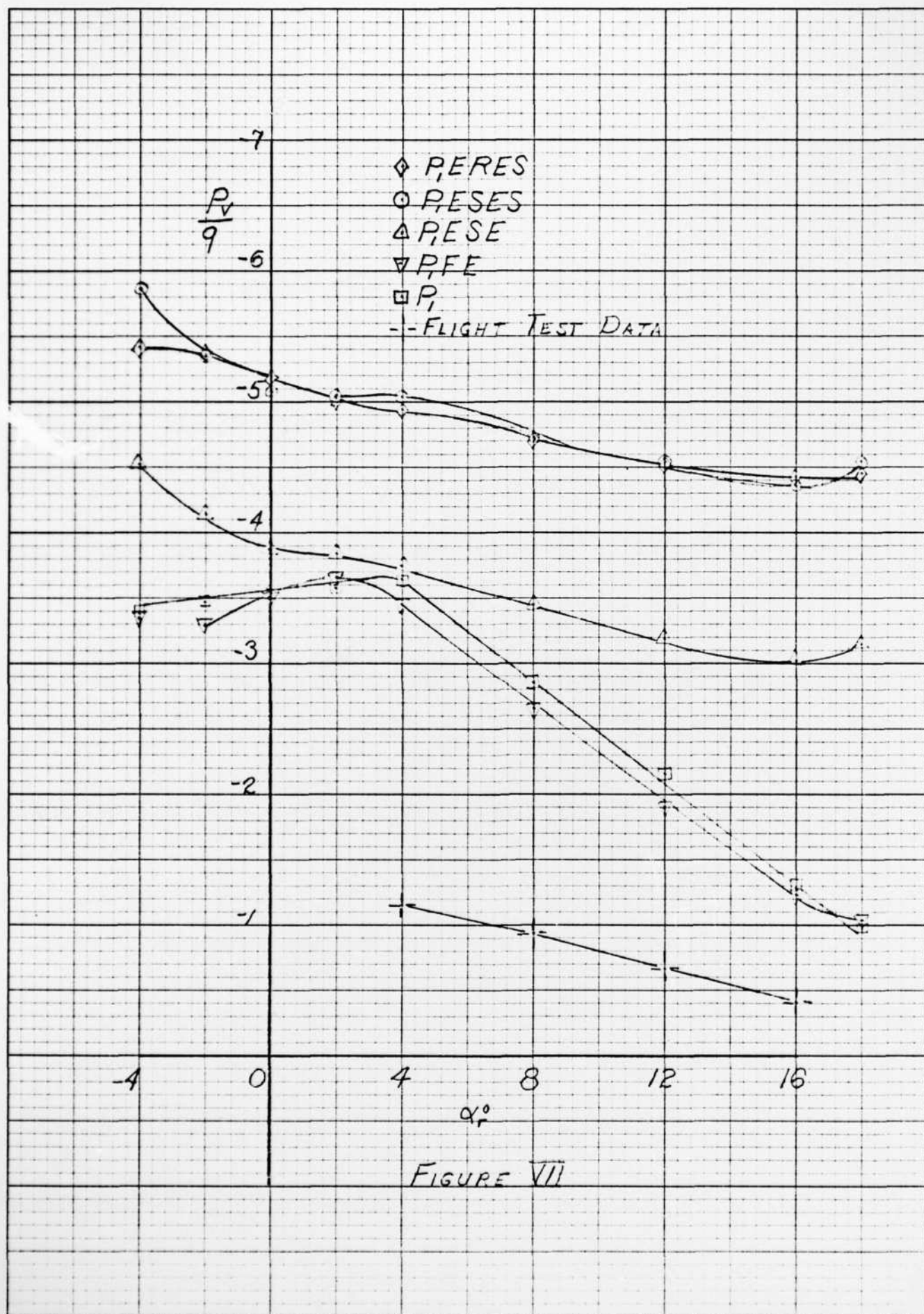
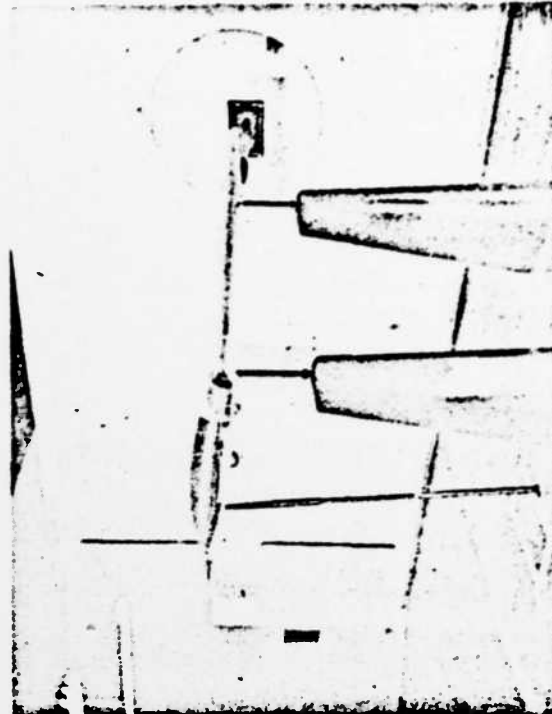
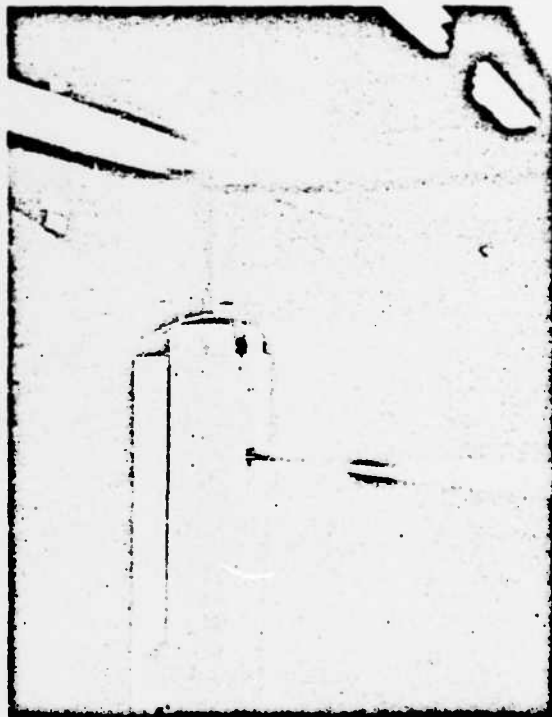
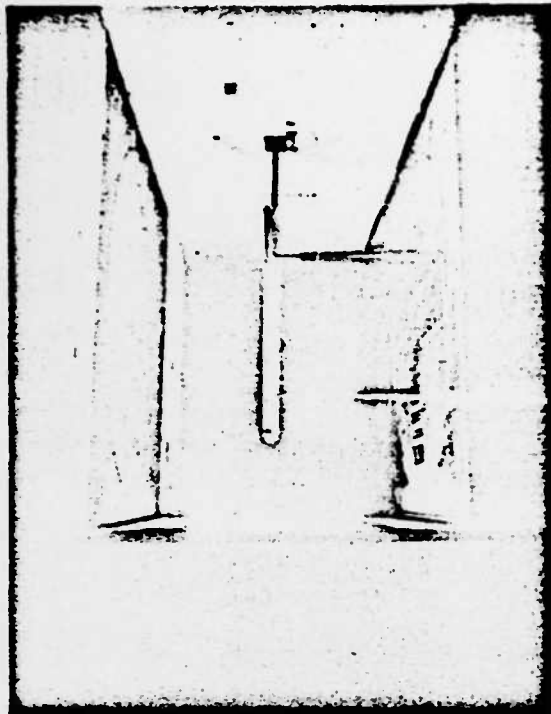
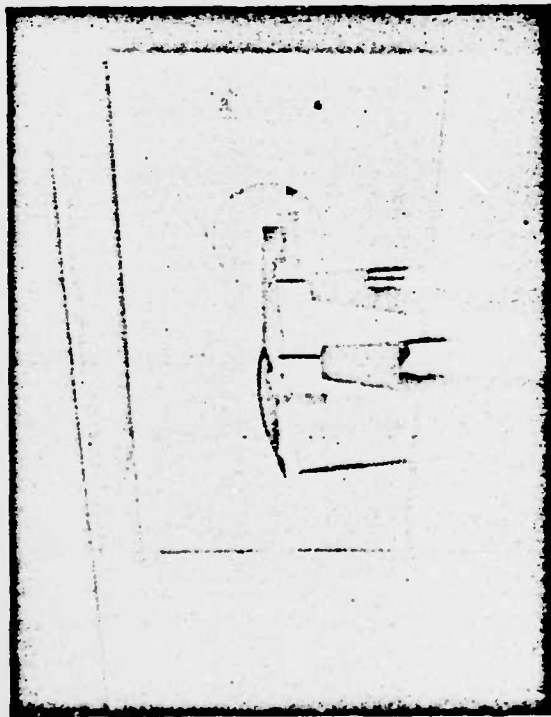


FIGURE VII

ONE FIFTH SCALE SEMI-SPAN CHEROKEE WING MODEL MOUNTED IN FORRESTAL 4' x 5' WIND TUNNEL
(DISCOLORATIONS DUE TO DARK PAINTED WING TIP, PLASTICINE AND TAPED SLOT EXITS)



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